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THE MISSION ORIENTED TERMINAL AREA SIMULATION FACILITY

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SUMMARY

A new simulation facility, the Mission Oriented Terminal Area Simulation (MOTAS), has been developed at NASA Langley Research Center (LaRC) that provides an Air Traffic Control (ATC) environment in which flight management and flight operations research studies can be conducted with a high degree of realism. An important requirement for the MOTAS facility was to provide the capability of real-time interaction between human controllers and simulator pilots during research studies. The MOTAS facility provides a flexible and comprehensive simulation of the airborne, ground-based, and communications aspects of the airport terminal area environment. This report is a discussion of the MOTAS capabilities and major components. The terminal area model, MOTAM (Mission Oriented Terminal Area Model), is described as well as the evaluation and justification of the facility. Details of the traffic management features of the terminal area model, human controller, and multicockpit capabilities are provided. MOTAS is currently operational with two cockpit simulators, four air traffic control (ATC) stations, four pseudo pilot stations (PPS), a metering and spacing system of traffic flow control management, and terminal area models providing two route structure environments. These two environments are area navigation (RNAV) for advanced equipped aircraft and vectoring for conventionally equipped aircraft.

INTRODUCTION

The major elements of the MOTAS facility are: an airport terminal area environment model, several aircraft models and simulator cockpits, four pseudo pilot stations, four air traffic controller stations, and a realistic air-ground communications network. The terminal area model represents the Denver Stapleton International Airport and surrounding area featuring an automated metering and spacing system of traffic flow management. Examples of the many other features are described in reference 1. The MOTAS facility combines the use of several cockpit simulators, pseudo pilot stations, and computer-generated algorithms for flying aircraft in the airport terminal area. Presently, the MOTAS facility is operational using the Transport Systems Research Vehicle (TSRV) Simulator and/or the General Aviation (GA) Simulator. Plans include the future integration of the DC-9 Full Workload Simulator and the Advanced Concepts Simulator after it becomes operational as a stand-alone simulator. These cockpit simulators will allow full crews to fly realistic missions in the airport terminal area. The remaining aircraft flying in the airport terminal area are flown through the use of the pseudo pilot stations or the computer-generated algorithms. The operators of these pseudo pilot stations can control five to eight aircraft at a time. The remaining major components of the facility are the air traffic controller stations which are presently configured to display and control the two arrival sectors, the final approach sector, and the tower and/or departure sector. The flexibility to be reconfigured according to research requirements enables the MOTAS facility to support a variety of flight vehicle and/or air traffic control system research studies which would not be possible in the real world due to safety, economy, and repeatability considerations. Each component of the facility will be discussed in detail in following sections of the report.

ACRONYMS AND ABBREVIATIONS

ACS	Advanced Concepts Simulator
ADAGE 1, 2	ADAGE Computer Graphics Systems
ASCII	American Standard Code for Information Interchange
ATC	Air Traffic Control
ATOPS	Advanced Transport Operating System
BAUD	Unit of signal speed equal to number of code elements per second
BYTE	Measurable portion of consecutive binary bits (usually six or eight bits)
CDC	Control Data Corporation
CDTI	Cockpit Display of Traffic Information
CPU	Central Processor Unit
CRT	Cathode Ray Tube
DASS	Digital Analog Subsystem
DEC	Digital Equipment Corporation
DECWRITER	DEC interactive hardcopy terminal
DICE	Direct Course Error
DMA	Direct Memory Access
DUII	Programmable synchronous interface
E&S	Evans and Sutherland Corporation
ECS	Extended Core Storage
EIA	Electronic Industries Association
FAA	Federal Aviation Administration
FIX	A geographic point flight objective
GA	General Aviation
G	Gate
I/O	Input/Output

IAF	Initial Arrival Fix
K	One thousand (1000)
LaRC	Langley Research Center
M&S	Metering and Spacing
MAP	Matrix Arithmetic Processor
MCR	Monitor Control Routine
MLS	Microwave Landing System
MOS	Metal Oxide Semiconductor
MOTAM	Mission Oriented Terminal Area Model
MOTAS	Mission Oriented Terminal Area Simulation
MPS	Multi Picture System
NAFEC	National Aviation Facility Experimental Center
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NSC	Network Systems Corporation
OM	Outer Marker
PPS	Pseudo Pilot Station
PPU	Peripheral Processor Unit
RNAV	Area Navigation
RTI	Research Triangle Institute
SST	Supersonic Transport
STAR	Standard Terminal Arrival Route
STOL	Short Take-Off and Landing
TAATM	Terminal Area Air Traffic Model
TCV	Terminal Configured Vehicle
TSRV	Transport Systems Research Vehicle
TTL	Transistor to Transistor Logic

UWD	The driver program that controls the actual physical transfer of data on the data channel (between CYBER and DEC computers) and operates in a PPU
200 UT	CDC Users Terminal Communications protocol
VHF	Very High Frequency
VOR	VHF Omnidirectional Range

HISTORY

The concept of flying fully manned aircraft simulators in realistic air traffic control (ATC) environments is not a recent development at Langley Research Center. In fact, this concept originated in the early 1960's when researchers were actively involved in the development of simulators for and the conducting of research with the various supersonic transport (SST) configurations. One of the earliest examples of this type of systems research is found in reference 2 where the Langley SST simulator was tied to the ATC simulation facilities at the Federal Aviation Administration's (FAA) Technical Center, formerly known as the National Aviation Facility Experimental Center (NAFEC), located near Atlantic City, New Jersey. Data transmission and communications between the two simulation sites were effected through the use of leased private telephone lines. During the time period of about 1963 to 1968, a number of experiments were conducted using these two facilities linked together. References 3 and 4 provide examples of experiments conducted during this period. During the time period of about 1972 to 1973, Langley once again linked one of its simulators to the FAA Technical Center. This time the research centered around the flying of a STOL aircraft in the realistic terminal area environment (ref. 5).

In 1971, Langley initiated a contract to develop a Terminal Area Air Traffic Model (TAATM, ref. 6). The intent of this model was to determine the effects on the overall system by introducing advanced control concepts and instrumentation. The model was capable of both real- and fast-time simulations and was defined to represent the Atlanta Hartsfield Terminal Area. Between 1971 and 1976, the model was improved and expanded (refs. 7-9). In 1976, it was converted to represent the Denver Stapleton Terminal Area and

work was begun on developing control algorithms to represent the microwave landing system and a fixed-path metering and spacing system (ref. 10).

In 1977, the Transport Systems Research Vehicle simulator (ref. 11) was interfaced with the TAATM simulation through a limited analog data link to explore the feasibility of terminal area systems studies. This effort was successful and a study evaluating an advanced transport, a microwave landing system, and a fixed-path metering and spacing system was conducted during the 1978-1979 timeframe (refs. 10 and 11). The success of this effort and the beginning awareness that a more realistic environment was required to perform flight management and flight operations research led to the development of the MOTAS concept.

Beginning in 1979, the elements which would become MOTAS began to take shape. These included a new version (Mission Oriented Terminal Area Model, MOTAM, ref. 1) of the TAATM simulation with many new enhancements and additions including requisite interface software for controller stations, pseudo pilot stations, and multicockpits. Also in 1979, work was begun to obtain a new advanced graphics system to generate the ATC controller displays. This equipment was delivered in 1981. In 1980, based on recommendations from the FAA Technical Center, Langley evaluated voice recognition technology (ref. 12) for use as an input device, instead of a keyboard, for the pseudo pilot stations. This evaluation proved the feasibility of this concept, and the equipment was ordered and subsequently delivered in 1981.

By late 1982, the elements of MOTAS were integrated for the first time to provide an operational facility. During 1983, the facility underwent an extensive testing period, and by mid-1984 the second simulator (General Aviation, ref. 13) was incorporated into the facility to allow the testing of multicockpit simulations.

INTEGRATION OF THE MOTAS COMPONENTS

Figure 1 shows the major elements of the MOTAS simulation which is briefly described in reference 14. The heart of the simulation is the terminal area model MOTAM (Mission Oriented Terminal Area Model) and is simulated on a CDC CYBER 175 computer. MOTAM simulates the ATC procedures, radar system, route structures, navigation aids, wind conditions, and up to twenty different classes of aircraft and their respective performance characteristics for the Stapleton International Terminal Area, Denver, Colorado. Also, MOTAM permits human controllers and pilots to interact with the automated terminal area scenario. Figure 2 presents the current configuration of the MOTAS Facility with two aircraft (GA and TSRV) simulated on one CYBER 175. The two CDC CYBER 175's perform real-time communications with one another through a specially designed area of external shared central memory called extended core storage (ECS). MOTAM transmits display and target aircraft status information to the ATC stations and pseudo pilot stations via medium-speed digital interfaces. Data can be sent in both directions; from the CDC CYBER 175's to the MOTAS facility and from the MOTAS facility to the CDC CYBER 175's. The ATC stations are simulated by two Evans and Sutherland Multi Picture Systems with a DEC PDP 11/44 as host computer. The pseudo pilot stations (PPS) are simulated with a DEC PDP 11/34 as host computer interfaced to four Threshold Technology Inc., voice recognition systems to provide voice commands to MOTAM aircraft targets. Also, an alpha-numeric keyboard can be used to enter commands to MOTAM aircraft.

At any time during the course of a terminal area scenario simulation, a cockpit simulator may assume the identity of an aircraft already participating in the scenario and begin to transmit its own flight parameters as those of the selected target aircraft. MOTAM transmits status information concerning

both the cockpit aircraft and the other terminal area aircraft to the ATC and PPS stations at four-second intervals which simulates the sweep of an ATC radar. This status information is subsequently displayed on the CRT's of these stations.

Human controllers may interact with the simulated controller algorithms of MOTAM via the ATC and PPS stations with varying degrees of authority. The human controller has several options available: (1) monitor the commands from the simulated controllers; (2) take complete control of the commands to one or more aircraft in the terminal area, while the simulated controller directs the remaining aircraft; and (3) take control of an entire sector, commanding all aircraft within the jurisdiction of the sector and relinquishing control of the aircraft as they pass into the jurisdiction of another sector. The control sectors include north arrival, south arrival, approach, and tower control. Human controller commands may be issued to terminal area target aircraft either by direct keyboard entry at the ATC stations or via voice input from the operator of a pseudo pilot station. Cockpit interface, human controller interface, and operational procedures are described in more detail in references 1 and 14.

THE TERMINAL AREA MODEL (MOTAM)

MOTAM is an independent adaptation of the Terminal Area Air Traffic Model (TAATM) as it existed in October 1979. The TAATM model has been under development for more than a decade and has been extensively documented in references 6 through 10. Modifications have been implemented to the TAATM model to create the terminal area model now called MOTAM in order to realize the objectives of the MOTAS facility. In particular, interfaces have been developed to permit human controllers and human pilots to interact with the computer-generated terminal area scenario. The MOTAM model is extensively documented in reference 1.

MOTAM features both a route structure geometry that reflects present-day paths in use at the Stapleton International Terminal Area and a system of traffic flow control called a fixed-path speed-control metering and spacing (M&S) system. The M&S control system concept was originally proposed by MITRE Corporation in 1975 and its development by NASA and RTI personnel is thoroughly documented in its TAATM model implementation in reference 10. Because the M&S control theory was designed for advanced-equipped aircraft with area navigation (RNAV) capability and because MOTAS facility objectives include servicing conventional as well as RNAV-equipped aircraft, two route structure geometries have been implemented. Both geometries utilize the fixed-path, speed-control, metering and spacing system of traffic flow management, but one provides an RNAV environment while the other features a route structure which utilizes vectoring techniques in the approach area. Figures 3 and 4 depict the two route structure geometries: RNAV environment and vectoring environment, respectively.

Referencing figure 3, the M&S RNAV terminal area geometry consists of four standard terminal arrival routes (STAR's). The paths assume primarily RNAV flight mode capability for advanced-equipped aircraft which may be commanded to fly from waypoint to waypoint through a direct engage command. The basic scheme of the arrival geometry is a "four corner post" pattern with initial arrival fixes (IAF's) at KEANN in the northeast, KIOWA in the southeast, BYSON in the southwest, and DRAKO in the northwest. Holding options are available at each arrival fix for aircraft needing a delay. Additional delay paths are provided in the arrival area for western routes at JASIN in the north and at BRISS in the south. The area of figure 3 which is defined by NORT1, FLOTS, WIFES, and SOUT1 is the dump or approach control area. It is in this area that all aircraft are merged into a final sequencing order based on outer marker arrival times.

Figure 4 features the flight path geometry of the vectoring terminal area model. The paths provide for VOR and vector flight mode capability, thereby accommodating conventionally equipped aircraft which require a vector command in order to make an appropriate heading change. As in the previously described route structure for the RNAV environment model, the basic form consists of a "four corner post" pattern with the same IAF's at KEANN, KIOWA, BYSON, and DRAKO where holding delay options are available. In contrast to the RNAV route structure, however, no provision is made for alternate delay paths in the arrival sectors of the western routes. Arrival delay paths were deemed to be unnecessary because of the much longer approach sector downwind paths that were configured into the geometry with choices of several vector paths extending toward the final approach course. For both the western and eastern routes, there are several alternate vector paths in the approach sector for additional delay spacing purposes. Figure 5 is an expansion of the vector model approach control area which illustrates the choices of vector

paths available to aircraft for delay spacing capabilities. The vector headings of the various paths are given in both magnetic and true north.

Metering and Spacing Speed Control Theory

The metering and spacing speed control logic of MOTAM regulates the flow of traffic into the terminal area and merges all aircraft into an optimum landing sequence. The criteria of the M&S system decrees that all aircraft reach their respective initial arrival fix (IAF) with adequate separation (metering) and that all aircraft conform to a master plan of assigned scheduled outer marker (OM) arrival times (spacing). These outer marker times are determined for each aircraft upon entry into the terminal area scenario. Subsequently, the simulated controllers of MOTAM make recommendations in the form of actual controller messages so that each aircraft may attain, as closely as possible, its scheduled OM arrival time. The recommendations are made dynamically at strategic locations (called control action points) along the flight path of each aircraft and include various methods of delay spacing and precise final spacing. An example of the control action points along a sample route is given below. Delay spacing techniques may include speed control, hold assignments, or alternate path selections (path stretching). At times, the landing order of aircraft may be resequenced. Precise final spacing is achieved through the direct course error (DICE) turn calculation in the approach area which determines exactly when an aircraft should perform a direct engage to next waypoint (RNAV model) or make a vector heading change (vector model) in order to meet its OM arrival specifications.

Control Action Points

Figure 6 depicts the metering and spacing control areas and control action points along the northwest DRAKO STAR of the RNAV environment model. At these control locations, certain simulated controller commands and recommendations are issued to an aircraft with the objective of realizing its scheduled outer marker arrival time. The control action points are delineated below:

1. 20-minute message - Enroute metering is performed while an aircraft is outside the 50-mile perimeter in order to regulate the flow of traffic entering the terminal area. When an aircraft is predicted to arrive at its destined IAF in 20 minutes, enroute control logic determines whether adequate separation can be maintained with the aircraft that is ahead of this aircraft and whether the aircraft may be accommodated within the current capacity of the terminal area. If the criteria of separation and terminal area capacity are met, then enroute control permits the aircraft to proceed. Otherwise, the needed enroute delay time is determined and a new IAF target time is issued to the aircraft. Subsequent enroute control logic attempts to realize this new target time for the aircraft.

2. 5-minute message - When an aircraft is predicted to arrive at its destined IAF in 5 minutes (as computed by the successful 20-minute control action), enroute control logic assesses whether or not the particular IAF holding stack has room for the aircraft to absorb any delay requirements that have been determined in its schedule. If no room exists in the holding stack, then the aircraft must remain in its enroute status and cannot be considered again for a 5-minute control action until the next 4-second equivalent of the radar sweep. If, on the other hand, the stack can accommodate the aircraft, then the 5-minute flight plan logic permits the aircraft to proceed and

subsequently performs initial scheduling and sequencing procedures for the aircraft. These procedures assign an initial scheduled outer marker arrival time for the aircraft allowing for separation criteria from previously scheduled traffic.

3. Radar acquisition - A perimeter entry time is calculated for an aircraft at the successful completion of a 5-minute control action. This time corresponds to the time that the aircraft would come within range of the terminal area radar, and it is at this point where flight dynamics are initiated for the aircraft. At subsequent 4-second intervals, the position of the aircraft will be updated, thus simulating the radar sweep time. Also at radar acquisition, an IAF hold assignment option is available as a delay maneuver for the aircraft.

4. Hold determination - Several miles from the DRAKO IAF, the M&S control logic determines for a final time whether to delay the aircraft via a hold assignment. If no hold is assigned, the aircraft is cleared inbound on the STAR. If assigned a hold, the aircraft is instructed as to the amount of time to delay in the holding pattern and when to expect further control directives. Aircraft schedule information is also updated.

5. Hold exit determination - Once the aircraft has fulfilled its hold delay requirements, the control logic determines whether additional holding delay needs to be imposed on the aircraft. If no such delay is deemed necessary, the aircraft is cleared inbound on the STAR. Otherwise, the new hold requirements are issued to the aircraft.

6. Speed control - Just past DRAKO IAF, the first opportunity for delay spacing via speed control occurs. M&S control logic computes an appropriate speed assignment in order to realize current delay requirements for the aircraft. Schedule information is once again updated at this point.

7. Speed control or path stretching - Just prior to reaching the waypoint at JASIN, two delay spacing options are available to the control logic. One is another speed control, and the other is the possibility of assigning a delay vector path to the aircraft.

8. DICE control to NORT1 - If the delay vector path is taken by the aircraft, a subsequent DICE control is performed in order to return the aircraft to the nominal path at NORT1 once sufficient delay has been achieved.

9. Firm sequencing - Shortly before reaching the waypoint at NORT1, the aircraft is handed off from arrival to approach control. The aircraft soon receives a final slot in the landing sequence. The control logic which establishes this final landing order comprises the firm sequencing algorithms, and, once implemented, does not permit any firmly sequenced aircraft to be resequenced in its landing plans.

When the aircraft enters the final sequencing area of approach control, it flies a downwind leg that is "stretchable" to NORT3. Once again, delay techniques are available in the form of the selection of a minimum, nominal, or maximum path off the downwind.

10. DICE control to merge point, MP - Although the landing order of firmly sequenced aircraft may not be resequenced, fine adjustments are possible in the schedules of these aircraft through the DICE control action. The DICE computation determines the precise timing for initiating one or more direct engage turns in order to realize the aircraft scheduled outer marker arrival time. The flexibility of the DICE allows for minor slippages in the aircraft schedules in either a forward or backward manner. The first DICE in this final sequencing area involves a turn off the downwind toward the merge point waypoint.

11. DICE control to the gate - A second DICE computation is performed for the aircraft as it seeks to turn toward the gate. As in the first DICE,

minor slippages are possible in the aircraft's schedule in either a forward or backward direction. After this final DICE turn, the aircraft is instructed to slow to approach speed and to contact tower control at the outer marker.

Human Controller Interface in the MOTAS Facility

Throughout the operation of the terminal area scenario, simulated controller algorithms are issuing commands to all aircraft in order to achieve the delay spacing and landing order goals determined by the M&S control system of algorithms. At any time, a human controller may issue a directive to a target aircraft, overriding simulated control directives, and the M&S system will subsequently accommodate the human command. The types of directives that may be issued by a human controller include: hold directive with specified amount of holding time at one of the initial arrival fixes, vector heading change, altitude change, and speed change commands. Additionally, the human controller may take charge of one or more specified aircraft and issue all commands to these aircraft, or he may assume command of an entire sector and issue directives to all aircraft within his sector of control.

ATC DISPLAY SYSTEM

Major components of the ATC display system are two Evans and Sutherland Corporation Multi Picture Systems (MPS) with a Digital Equipment Corporation (DEC) PDP 11/44 minicomputer (appendix A) as host for both display computers. The MPS, described in more detail in appendix B, is a general-purpose, refresh, stroke-writing computer graphics system designed to support several users simultaneously with the capability of generating images of two-dimensional or three-dimensional objects displayed on a large, round CRT. Several nonstandard, special features developed for NASA Langley's MPS's to accommodate ATC applications are: ATC symbology; 23-inch, round, flat-faced CRT's; and modified communications software. Figure 7 is a block diagram of the ATC display system showing data flow and subcomponents. The host computer is linked to both real-time CDC CYBER 175's via two medium-speed serial interfaces. Each interface is capable of sending or receiving data to or from the CYBER 175, although operationally one line is programmatically dedicated for sending, and one for receiving. A discussion of the CYBER/DEC computer interface can be found in Appendix C. Each MPS has a full complement of interactive devices which are listed in appendix B of this report. Major software consists of an RSX-11M disk-based operating system, a MACRO-11 assembler, a FORTRAN compiler, a MUX200 communication package, device drivers, maintenance diagnostics, and MPS graphics subroutines. Figures 8, 9, and 10 are photographs of the ATC hardware. Figure 8 is of the total system, figure 9 is a single MPS with interactive devices, and figure 10 is of the DEC PDP 11/44, disk, and DECWRITER.

PSEUDO PILOT STATIONS

The pseudo pilot station (PPS) is used by an operator to direct the flight of several aircraft targets through a controlled sector of airspace. The primary devices used by the operator are the voice communications link to talk to the air traffic controller and to the central computer by way of a voice data entry unit; and a CRT terminal which displays the information on all aircraft under his command.

The MOTAS Facility has four identically equipped pseudo pilot stations, each housed in a separate cubicle for sound isolation. Figure 11 is a block diagram of a typical pseudo pilot station, and Appendix D presents details on the capabilities of the pseudo pilot station equipment.

Operational Scenario

Preoperational - Sometime prior to the operational run period, the pseudo pilot station operator must "train" the voice recognition unit to his voice for each word of vocabulary that will be used. In this mode, the CRT terminal is switched to the voice recognition system. During the training mode, the operator will assign an ASCII character or a string of such characters to each word of the vocabulary. After all words of the vocabulary have been entered, the operator's voice patterns and the assigned ASCII output characters are recorded on a cassette tape for later use. This assignment is made through the keyboard with CRT prompting from the voice recognition system. For more details on this subject, see reference 12.

Operational - During the setup time prior to an operational run period, the PPS operator will: initialize the voice recognition unit by loading his voice patterns from the cassette tape, switch the voice

recognition unit data communications port to connect with the interface computer, and switch the CRT terminal to connect with the interface computer.

When the run period starts, the CYBER 175 computer will transmit the information necessary to provide the CRT display with target information. This information is formatted by the DEC PDP 11/34 computer before it is sent to the CRT display. Figure 12 is a layout of the information as presented on the CRT screen.

The air traffic controller contacts the PPS operator by voice communications when a command to one of the controlled targets is required. The communications dialogue is typical of the air-to-ground communications between the controller and an aircraft pilot. Once the command message has been received by the PPS operator, the operator mimics the command to the voice recognition unit using the very rigid dialogue that is constrained by the trained vocabulary voice patterns. As each word is recognized by the voice recognition unit, the ASCII character string assigned to that word is transmitted to the DEC PDP 11/34 computer. Each word of the command message is saved in the DEC PDP 11/34 computer until the PPS operator sends a special ASCII character signaling the end-of-message. The DEC PDP 11/34 computer then sends the entire message back to the CRT terminal where it is displayed in the scratchpad portion of the CRT display screen (fig. 12). At this time, the PPS operator can either: cancel and retransmit the message if errors are detected; or he can signal the DEC PDP 11/34 computer with another special ASCII character that the message is to be transmitted to the CYBER 175 computer.

As shown in figure 12, the upper right portion of the formatted display contains a listing of the commands to be used. These serve as prompts to the PPS operator.

VOICE COMMUNICATIONS

Several classes of voice communications are utilized by the MOTAS facility. These include the following:

1. Air-to-ground communications that involve the air traffic controllers, simulator pilots, and pseudo pilots during the air traffic control simulation.
2. Controller-to-controller intercommunication to allow messages to be passed between the various controllers without being heard on other voice communications links.
3. Communication between computer operators is used during pre-run periods to allow program initialization.

The MOTAS voice communications are achieved by enhancements to the existing LaRC Simulation Intercommunication System. Figure 13 shows a block diagram of the MOTAS Voice Communications System and appendix E presents details on this system.

Since the Simulation Intercommunication System is the central part of the MOTAS voice communications, a brief description of that system will be given. The Simulation Intercommunication System provides all the voice communications for the LaRC Simulation Complex. Each type of station (simulator, computer operator, equipment operator) is equipped with one or more of the following sensor devices: a headset with a push-to-talk boom microphone; a hand-held microphone with push-to-talk; and a speaker with volume control. Each station is cabled to central equipment racks that contain the amplification and push-to-talk muting circuits. All stations terminate on a patchboard in the equipment racks. The patchboard contains not only the station terminations but also conference buses that allow connecting up to 12 stations into a single conference line. In normal simulation operations, a conference bus is

made up of the simulator stations, computer program operator station, and any additional devices such as the Visual Landing Display System and/or one or more ADAGE Graphics Computers.

The MOTAS Voice Communications System contains the following Simulation Intercommunication System stations: Four air traffic control stations, four pseudo pilot stations, and up to four computer operator stations. Enhancements that have been added for the MOTAS Facility are:

1. A 4 by 5 switching matrix that allows one or more, up to a maximum of five, simulator stations to be connected to one of the four controller stations. Control of the matrix elements is a function of the communications frequency selected by the simulator pilot.
2. An independent intercommunication that allows the controllers to pass voice messages among themselves.
3. A push-to-talk detect system that provides inputs to the CYBER 175 computer to allow recording the number of messages transmitted from a station for post-run statistical evaluation.
4. Microphone switching at each pseudo pilot station to allow the station operator to communicate with either the air traffic controller or to the CYBER 175 computer via a voice data entry system.

CONCLUDING REMARKS

The MOTAS Facility has been developed to provide an ATC environment for flight management and flight operations research studies. The facility has the flexibility to be reconfigured to permit alternate terminal area environments and has enhancements to provide human controller and human pilot capabilities to meet varying research requirements. Two cockpit simulators have been incorporated into the facility (TSRV and GA). The DC-9 Full Workload and Advanced Concepts Simulators will be interfaced to the system at a later date. Examples of research planned for the facility include traffic flow management studies and data link information transfer studies.

One study using partial capabilities of the facility was conducted with the DC-9 Full Workload Simulator. The primary purpose of this study was to evaluate candidate procedures for utilization of Cockpit Display of Traffic Information (CDTI) and determine the resulting impact on normal crew procedures and workload. For this study, a single air traffic control station was required and the MOTAM program was replaced by prerecorded traffic stored at 1-second intervals on a data file. The data file was structured to emulate the output of MOTAM.

In the near future, MOTAS will be used to provide an ATC environment for a series of studies using the GA and TSRV cockpit simulators to define guidelines for flight crew interface with the MODE S data link which will come into service as part of the FAA's NAS Plan implementation. Selected MODE S data link display formats and crew interfaces will be studied and flight technical error, pilot comments, and pilot workload, performance, blunders, and eye scan data will be collected.

APPENDIX A

HOST COMPUTER ARCHITECTURE AND SOFTWARE

HOST COMPUTER

The host computer is a DEC PDP 11/44 fourth-generation mid-range computer with 16-bit data words and provides 22 bits for memory addressing. Memory size is 256K bytes and is expandable to 1 megabyte. Other features include: 8K byte cache memory, extended instruction set, floating point processor, dual disk drive, dual cartridge tape drive, and console terminal. Software that is resident on the host includes the operating system, compiler, assembler, communication package, device drivers, maintenance diagnostics, and the MPS graphics software. More detail of the host computer is discussed in reference 15.

DEC's data bus, the UNIBUS, enables devices to send, receive, or exchange data without processor intervention and without intermediate buffering. The DEC PDP 11/44's processor acts as an arbitration unit for the UNIBUS control by regulating bus requests and transferring control of the bus to the requesting device with the highest priority. The central processor contains arithmetic and control logic for fixed-point arithmetic with hardware multiply and divide, test and branch operations, and control operations. Also, the processor provides room for a floating point processor and UNIBUS options. The DEC PDP 11/44 operates in three modes: kernel, supervisor, and user. In kernel mode, a program has complete control of the machine; when in any other

mode, the processor is inhibited from executing certain instructions and can deny direct access to the peripherals on the system.

OPERATING SYSTEM

The operating system, RSX-11M, is a disk-based system used both as a multiprogramming and as a real-time system. THE RSX-11M operating system is described in reference 16. It can operate as a standalone computer (for quick response) controlling one process or as a multiuser computer supporting several terminals. The software interface between the user and RSX-11M is known as Monitor Console Routine (MCR) and will be discussed in more detail later. RSX-11M will support FORTRAN IV or FORTRAN IV-PLUS, MACRO-11, BASIC-11, BASIC-PLUS-2, COBOL, and CORAL-66. Langley's system has FORTRAN IV-PLUS and MACRO-11. RSX-11M real-time and multiprogramming operations require interaction of the following system elements:

Memory - hardware storage element.

Executive - operating system software that directs all program execution.

User and System Programs - RSX-11M executable programs called "tasks."

MCR INTERFACE

As stated earlier, MCR serves as an interface between the operating system and user. MCR reads or parses the user input command and services the command by loading an MCR overlay or by activating an independent task. The fundamental executable unit of the RSX-11M system is the task and each task is privileged or nonprivileged. MCR provides privileged users with functions that control and modify system operation as well as functions that permit program development and system maintenance. MCR provides nonprivileged users

with only program development and local maintenance. A brief summary of MCR command functions are listed below:

Initialization Functions - assign, boot, mount, unmount, flags, install, load, unload, set, create user file directory.

Informational Functions - display active tasks, devices.

Task Control Commands - run, abort, cancel, reassign, redirect, remove, stop.

System Maintenance Commands - pass control, send messages, open, save.

Multiuser Protection Commands - allocate devices, log on, log off, de-allocate.

Task Builder - The task builder creates an image called a task by linking one or more object modules. This image can then be installed and run by using appropriate MCR commands. The object modules usually include those created by a compiler or assembler and those which contain system or user library routines. The task builder performs the following:

- (1) links object modules
- (2) resolves references to system
- (3) allocates virtual address space to the task
- (4) produces a task builder map
- (5) produces a symbol file
- (6) builds an overlaid task
- (7) maps the task to shared regions of memory

SYSTEM UTILITIES

The RSX-11M operating system provides several utilities to work with different kinds of files, the contents of those files, and different kinds of

media (disks, magnetic tape, and cassettes). Listed below are several categories of RSX-11M utilities:

DEC Editor (EDT) - EDT is an interactive text and source editor for creating and maintaining text files. EDT provides unlimited access to an entire file at one time and provides character-mode editing.

Line Text Editor (EDI) - EDI is a line-oriented, interactive editor used to create and maintain text and source files.

Peripheral Interchange Program (PIP) - PIP is a file utility program that transfers data files from one Files-11 (describe below) device to another. PIP also performs file control functions (copy, delete, rename, list file directories, unlock-files, and spool files).

File Transfer Program (FLX) - FLX is a file utility program that transfers files from one volume to another. Also, FLX performs file format conversion (when necessary) during data transfer.

FILES-11

Files-11 is an RSX-11M software system that oversees the storage and handling of files on volumes which are magnetic media (disks, DEC tapes, and magnetic tape) that has been specially formatted by MCR functions. Five MCR commands that prepare volumes for Files-11 are: volume Format Utility (FMT), Bad Block-Utility (BAD), Initialize Volume (INITVOL), Mount (MOU), and User File Directory (UFD). When a file is created, the system places the file name in a User File Directory (UFD) and stores the user's current User Identification Code (UIC) in the file header to indicate the owner of the file. Usually, the UFD corresponds to the owner UIC; however a file can be listed in a UFD that is not related to the owner code. It is also possible to list the

file in more than one UFD. The Files-11 major functions are to generate file directories, establish file ownership, and provide file protection.

APPENDIX B

MAJOR ELEMENTS OF MULTI PICTURE SYSTEM

The Multi Picture System (MPS) is a high-speed, microprogrammed, general-purpose, interactive computer graphics system which displays pictures of three-dimensional objects to one or more users, each independently interacting with his picture (ref. 17). The MPS is a stroke writing system with high-performance dynamic capability for real-time motion (translation, rotation, zoom). The specific system at Langley consists of two MPS's with a DEC PDP 11/44 minicomputer as host. The host is referred to as a picture controller in the manufacturer's documentation. Major components of each MPS are shown in figure 14 and are listed below.

CENTRAL GRAPHICS PROCESSOR

The Central Graphics Processor (CGP) consists of a picture processor, picture memory, and picture generator. The Picture Processor is a high-speed, microprogrammed, digital arithmetic processor that accepts two-, three-, or four-dimensional (scaling) data; transforms the data; clips the data on six sides; and performs perspective calculations and viewpoint mapping on the processed data. This data is then output for subsequent display. The Picture Processor consists of the three following units:

- (1) An input controller receives data from the host computer and channels data to the matrix arithmetic processor (MAP).
- (2) The output formatter receives the processed data from the MAP and outputs the data formatted for display.

- (3) The MAP is the major unit of the picture processor and consists of a transformation matrix, transformation matrix stack, parameter register file, and an arithmetic unit.

The Picture Memory is a dual-port MOS memory with a 16-bit, 64K capacity. Memory use is a function of the user's application. Typically, a portion of the memory serves as a refresh buffer with double-buffer mode or segmented-buffer mode.

The Picture Generator generates images for the display and manages input/output of the interactive devices. Also, it converts digital data to analog signals for line drawing on the CRT display. Elements of the picture generator are:

- (1) The refresh and device processor controls refresh of the picture and performs interactive device input/output.
- (2) The character generator accepts and interprets the character code from the refresh and device processor and produces strokes which are sent to the line generator for display. The character generator interprets the full 128 ASCII character set for display of the 95 displayable ASCII character subset and performs positioning commands. The character generator can be programmed by the user to produce alternate character fonts known as special symbols. The generator has a memory, half of which is preprogrammed to interpret the standard ASCII character set and the other half of which is available for the user-defined special symbols.
- (3) The line generator receives data detailing coordinate point positions, status information which describes the modes of operation, and character codes that are passed to the character generator for interpretation. This information is used to produce the final image seen by the viewer.

PICTURE DISPLAY

The picture display receives analog signals from the picture generator for x-y positioning of the electron beam of the CRT. The z signal is used for controlling the beam intensity. Langley's displays are large (23 inch) round, flat-faced, monochromatic CRT's manufactured by XYTRON.

INTERACTIVE DEVICES

All MPS interactive devices are interfaced directly to the picture data bus. Data may be input from the device by the control program using direct I/O path of the picture controller interface. These devices may be used under interrupt control, polled directly by the applications program, or sampled once per refresh cycle by the refresh and device processor. Devices provided are typical of state-of-the-art display systems and offer ample graphical interaction for most applications. These are: data tablet, control dials, joystick, lighted function buttons, alphanumeric keyboards, and light pen.

PICTURE DATA BUS

All MPS components and interactive devices are connected to and interact with each other on a single high-speed synchronous data bus. The data bus allows coordinates to be transferred from the host to the picture processor concurrent with transfer of data from the picture processor to the picture memory and from the picture memory to the picture generator for display. Also, data is received from the interactive devices and may, or may not, cause interrupts to the picture controller. Data flow is supervised by a bus arbitration system which is integral to the bus.

PICTURE CONTROLLER INTERFACE

The picture controller interface connects the central graphics processor to the picture controller (host) via two paths--direct I/O and direct memory access (DMA). The direct I/O path passes single-word commands to or from the central graphics processor. The DMA path provides a means for block transfer of data to or from the central graphics processor without direct supervision by the host. The picture controller interface also provides interrupt capabilities for management of MPS components and interactive devices.

APPENDIX C

DESCRIPTION OF THE CYBER/DEC COMPUTER INTERFACE

One of the tasks was to develop the MOTAS facility interface between DEC PDP-11 series minicomputers with the real-time CDC CYBER 175 computers. The only available communications software for interfacing a DEC PDP-11 series computer with a CDC CYBER is the MUX200/RSX-IAS Emulator. The standard MUX200 was designed to support up to 16 simultaneous users. For a single user, this configuration is CPU- and memory-inefficient. Therefore the MUX200 was modified to service only one user which eliminated several subtasks decreasing memory requirements by 75 percent and significantly reducing CPU time. Also, this modification made it possible to have two copies of MODMUX installed in memory; one for receiving data and one for sending data. Figure 15 shows the hardware link and software involved in connecting the DEC mini's with CDC CYBER 175's. The standard MUX200 is on the system disk and can be installed in memory for transferring files between CYBER's and DEC mini's in the non-real-time mode.

STANDARD MUX200 EMULATOR

The user may communicate at command level with a host CDC CYBER or 6000 series computer. Also, using the RSX-IAS supported devices, jobs may be sent to and results received from the host. The subsystem consists of the following seven tasks and figure 16 shows intratask communication.

The MUX200 task controls the operation of the subsystem and handles all terminal input/output. All other tasks within the subsystem communicate via

this task. Communication is effected by the use of Send/Receive directives and global event flags. Large amounts of data are transferred in big buffers which are situated in the MUXCOM data area.

The ...MUX task informs the MUX200 task that an emulator user wants to be connected to the subsystem. It is started by the user typing the command "MUX" in response to the MCR prompt.

MUXINP and MUXOUT tasks are the input/output tasks of the subsystem and emulate the 200 UT card reader and line printer respectively.

MUXTTS tasks is the terminal spooler task and is used to save and restore data received by the subsystem from the CYBER.

CD.... task is the handler task and is used to control the synchronous link to the CYBER. The handler emulates the protocol of a CDC 200 UT.

MUXCOM is the common data area of the subsystem. The input/output tasks and MUX200 are linked to MUXCOM during task build. The handler also accesses this area.

MODIFIED MUX200

The primary purpose of modifying the standard MUX200 was to provide a real-time, single user environment for the MOTAS project. This modification included the elimination of tasks that are necessary for the multiuser environment, and since intertask communication provided by task MUX200 was no longer required, it was significantly reduced in size. Task configuration of the modified MUX200 is shown in figure 17. Secondly, a set of FORTRAN-callable subroutines was developed to allow the user to interface his application program with the modified MUX200 communication package. These routines are:

- (1) Subroutine CONECT connects the user's application program to the modified MUX200 emulator software.
- (2) Subroutine MXSEND takes a buffer of data from the applications program, moves the buffer to an emulator big buffer, and sends a message to task MUX200 indicating buffer address and length.
- (3) Subroutine MXRECV allows the applications program to receive a data buffer which has been transferred from the host CYBER 175 through the emulator.
- (4) Subroutine DISCON disconnects the applications program from the modified MUX200 emulator software by aborting all required RSX-11M tasks.

CYBER COMMUNICATIONS SOFTWARE

The CYBER communications software supporting MOTAS consists of two packages, one for the central processor and one for the peripheral processor. The central processor software consists of two main routines: one to initialize communications lines and the other to transmit and receive data during real-time operation. The peripheral processor program and the central communication subroutines communicate through an I/O table which resides in the MOTAM applications program. This table supplies buffer areas and port assignments. The PPU program (modified UWD, ref. 18) is connected to four synchronous lines via a multiplexer. These lines run synchronously at 9600 baud using 200 UT protocol.

DU11 INTERFACE

The DU11 interface is a single line, program controlled, double-buffered communication interface. It provides serial-to-parallel and parallel-to-serial data conversion, EIA-to-TTL and TTL-to-EIA voltage level conversion and modem control for full or half duplex communication systems. The DU11 is compatible with all DEC PDP-11 family computers. The basic version is compatible with the Bell 201 synchronous modem or equivalent. Interface operation is completely program controlled. The mode of operation, synchronous or asynchronous, character length, sense, sync character configuration, and duplex mode are all selected via the program. Maximum baud rate for synchronous communication is 10,000.

APPENDIX D

DESCRIPTION AND CAPABILITIES OF THE PSEUDO PILOT STATIONS

Referring to figure 11, the hardware devices that make up a pseudo pilot station are as follows:

VOICE RECOGNITION UNIT

These units are Threshold Technology, Inc., Model T600. Each unit consists of the following components:

- (1) A voice recognition system that is based in a DEC LSI-11/23 micro-computer. This system accepts voice inputs from a microphone, extracts speech parameters, and converts these to signals that are compared with a stored reference pattern to determine which, if any, of the vocabulary words have been spoken. When the system recognizes a word, it will output to the central computer program the string of characters that have been preassigned to that word during a training session.

The stored reference patterns are obtained during a nonoperational training session where the operator who will use the system speaks each word of the vocabulary to be used ten times. The vocabulary size can range up to 140 words or utterances. The voice patterns, along with a string of ASCII characters to be output when a word is recognized, are permanently stored on a cassette tape cartridge for later playback into memory.

- (2) A cassette tape recorder which is used by the operator for storage and playback of the voice patterns and output character strings for the vocabulary to be used by a particular operator. This capability allows multiple operators to use the same equipment with only short intervals between each user to allow loading the new user's tape.
- (3) A voice input module which is part of the voice communications station that will be described more fully in a following section. The voice input module provides preamplification of the microphone signal input, and has controls which allow the operator to set the microphone signal level for his speech input. A meter is provided to allow the operator to see the relative level of his voice output.
- (4) A CRT/keyboard terminal which is a commercially available CRT terminal (Ann Arbor Model 400E). The terminal is equipped with a standard 72-key detachable keyboard and a 15-inch CRT display that allows up to 24 lines of text at 80 characters per line.

The terminal has a switch for dual use modes. In the operator training mode, it is connected to the T600 computer unit. In this mode, the keyboard is used as the computer control unit for entering the operator's prompts and output character strings. The CRT is used in the training mode as an aid to direct the operator through the training session and to provide prompting during the actual training.

The second mode of use for the CRT terminal is the operational mode when the terminal is connected to the DEC PDP 11/34 computer. In this mode, the CRT display provides the operator with the information on all aircraft under his control, provides a scratchpad area for editing input commands prior to entering the command to the CYBER 175 computer program, and provides a prompting list of valid commands. In this mode, the keyboard can be used as

an optional means in lieu of the voice input to enter the characters that make up a command.

VOICE COMMUNICATION STATION

This station allows the PPS operator to communicate with the air traffic controller. The microphone for this station, as previously described, is used for two purposes: to talk to the air traffic controller (ATC position), and to "talk" to the CYBER 175 computer program through the voice recognition unit (VR position). A switch on the headset permits the operator to select the recipient of his voice output.

Another feature provided at this station is the generation of the push-to-talk discrete function. Each time the operator selects the ATC position for a voice transmission, a push-to-talk discrete is generated.

CYBER 175 COMPUTER INTERFACE

A DEC PDP-11/34 is used as the data communications interface between the CYBER 175 computer and the devices that make up the pseudo pilot stations. The DEC PDP 11/34 computer handles all aspects of the data communications to the CYBER 175 computer.

APPENDIX E

DESCRIPTION AND CAPABILITIES OF THE VOICE COMMUNICATIONS SYSTEM

Following is a description of the capabilities provided at each of the various station types in the MOTAS facility:

Air Traffic Control Stations - Four communications stations are provided, one at each of the air traffic controller work areas. Each of these stations is provided with a headset, microphone, speaker, and a communications control station. Four pushbuttons on the communications control station provide the means for assigning that station to one of four communications frequencies, each frequency representing one control sector such as Tower Control, Approach Control, North Arrival Control, and South Arrival Control.

A second set of pushbuttons on the communications control station provides the controllers intercommunication selection that allows one controller to talk to another without being heard on the air-to-ground communications lines.

Pseudo Pilot Stations - There are four pseudo pilot stations in the MOTAS Facility, each identically equipped with audio control and communications capability. Each pseudo pilot acts as a message relay intermediary in that he accepts verbal commands from the air traffic controller and relays these commands in a highly rigid format to the CYBER 175 computer program that generates the ATC radar targets. The messages are relayed to the computer by a voice recognition system.

Under normal operations, each pseudo pilot communicates exclusively with one air traffic controller; therefore, the communications lines from the pseudo pilot station are connected to the assigned air traffic controller's

communications lines at a conference bus on the Simulation Intercommunication System patchboard.

A switch is provided at each pseudo pilot station to allow the operator to control the destination of his voice output: he can talk to the air traffic controller, or he can "talk" to the computer-generated aircraft radar targets under his command through the voice recognition system at his station.

Simulator Stations - For the MOTAS program, existing simulators such as the DC-9, TSRV, and GA are used. Voice communications via the Simulation Intercommunications System exist for each of these simulator stations. Under normal research operations, the simulator pilot has voice communications primarily with the real-time computer operators; when used with the MOTAS program, the simulator pilot has voice communications primarily with the air traffic controllers. Since the simulator will fly through several control sectors, the pilot must be able to switch from one air traffic controller to another as he passes from control sector to control sector. The communications switching subsystem of the MOTAS Voice Communications System allows the pilot to select the controller with whom he will communicate. Each simulator is equipped with a communications frequency select tune head that provides the control output to the switching matrix elements. The pilot must select the proper frequency on his communications tune head in order to connect with the air traffic controller.

In addition to an air-to-ground voice communications line, each simulator is equipped with a second communications station that allows the program researcher to privately communicate with the real-time computer operator.

Real-Time Computer Operator Stations - Each real-time computer program requires an operator control station. For the MOTAS program the stations required are:

- (1) Piloted simulator control stations, one for each active piloted simulator being used, are required. These stations provide the program researcher to real-time operator communications.
- (2) A MOTAM program control station is required. The operator of this program must communicate with several stations at different times. The operator is provided with a switching control station that allows selecting one of the following:

Controller #1

Controller #2

Controller #3

Controller #4

Real-Time #1

Real-Time #2

Real-Time #3

The switching to these stations is accomplished through the MOTAS voice switching unit.

Other stations - Other stations that usually run with the piloted simulation programs are: ADAGE 1, ADAGE 2, and VLDS. These stations are existing intercomm stations. Voice communications are between these station and with the real-time simulator program operator.

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MISSION ORIENTED TERMINAL AREA SIMULATION

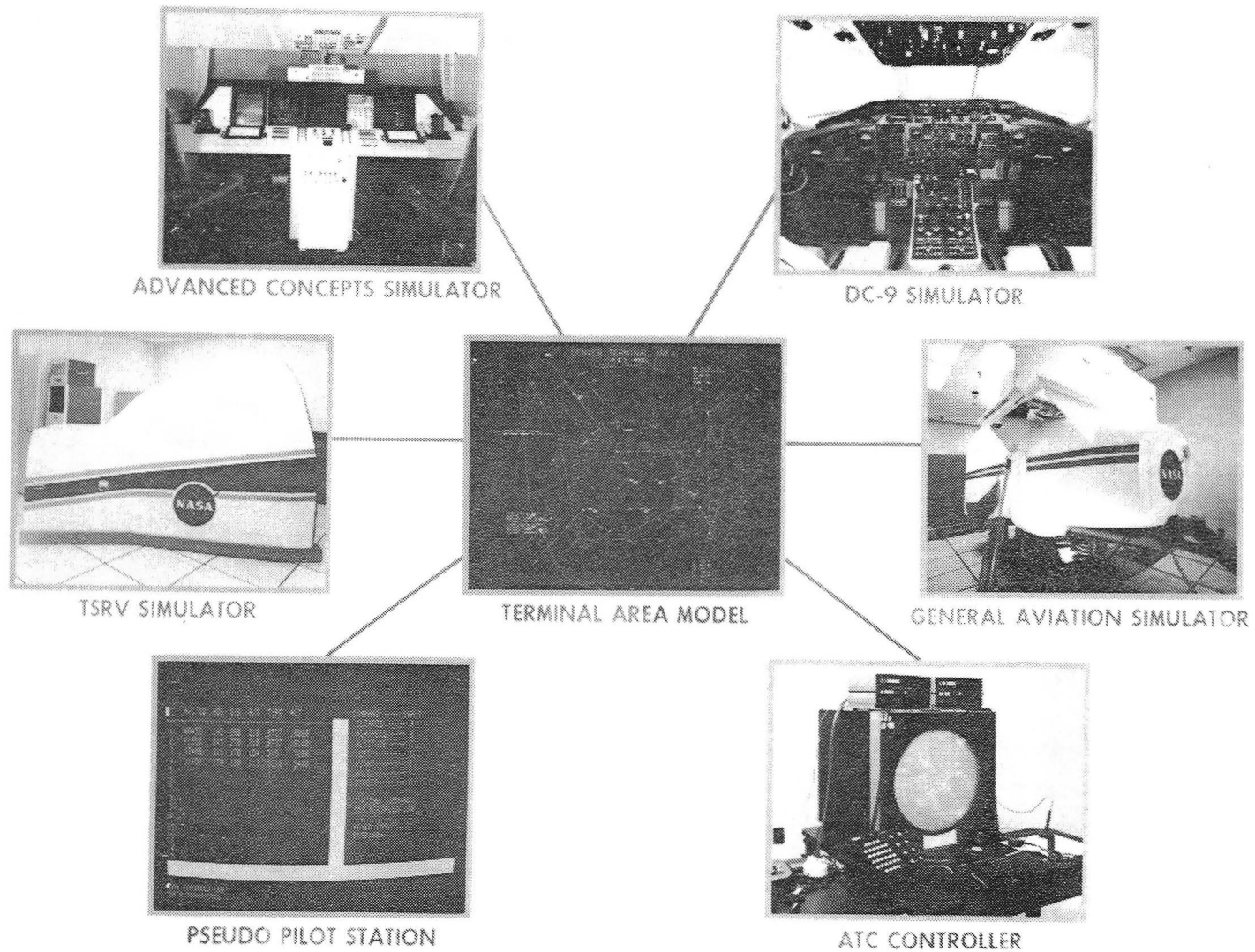


Figure 1. - Major elements of the MOTAS Facility.

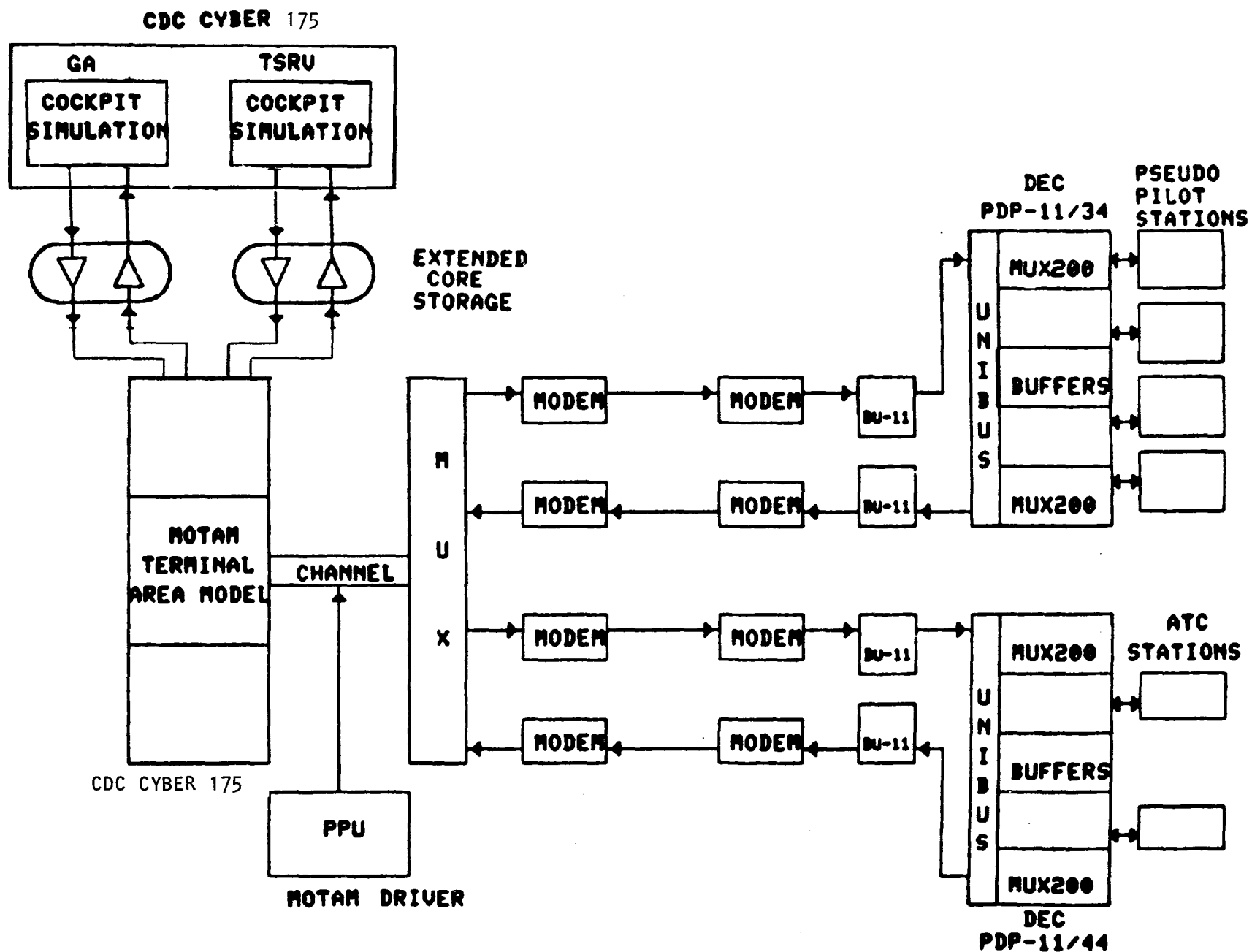


Figure 2. - Current MOTAS facility configuration.

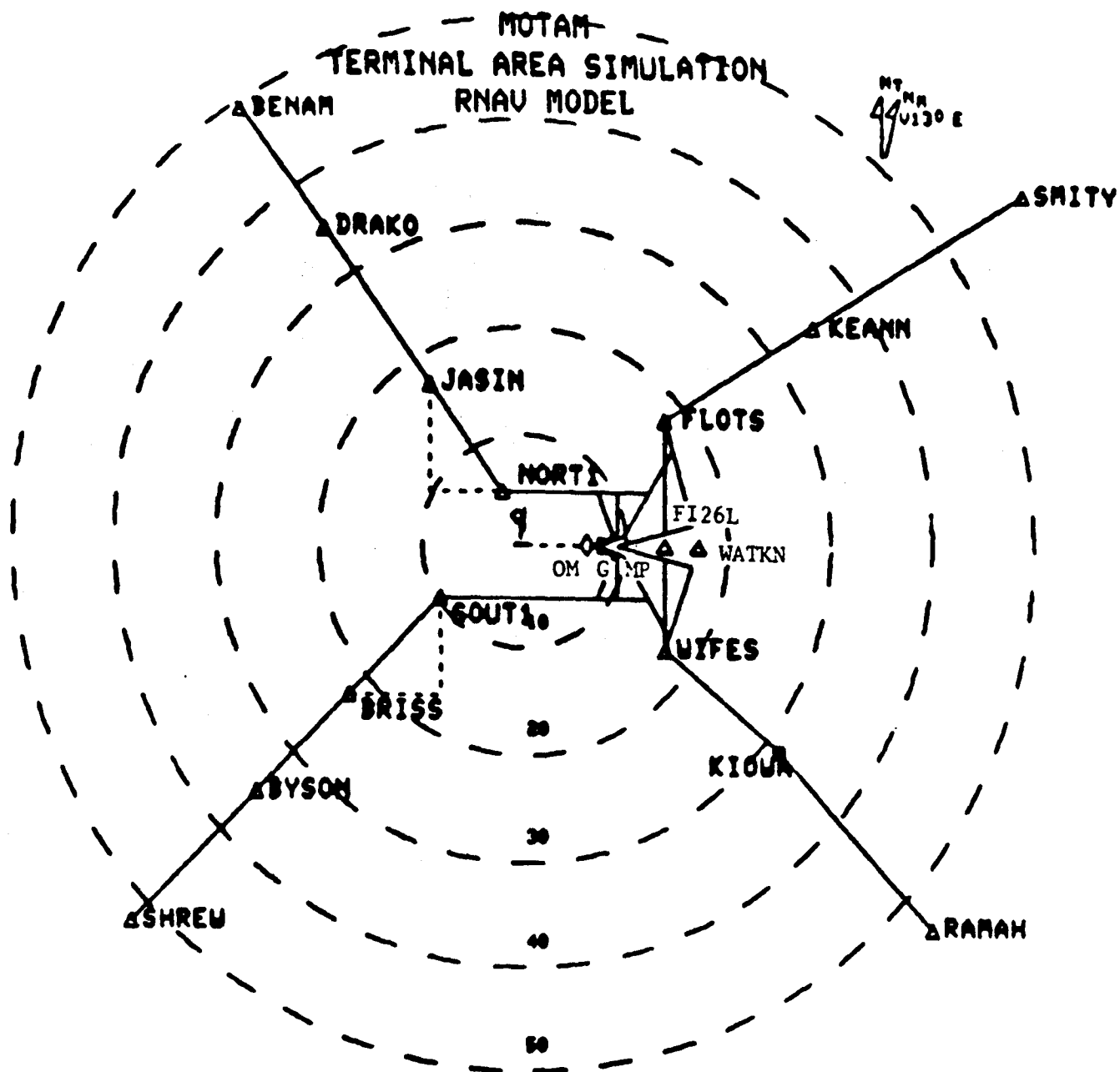
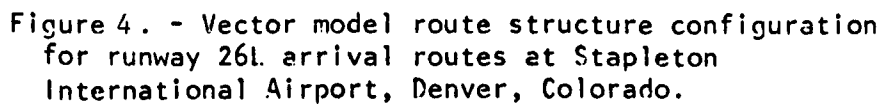


Figure 3. - RNAV model route structure configuration for runway 26L arrival routes at Stapleton International Airport, Denver, Colorado.



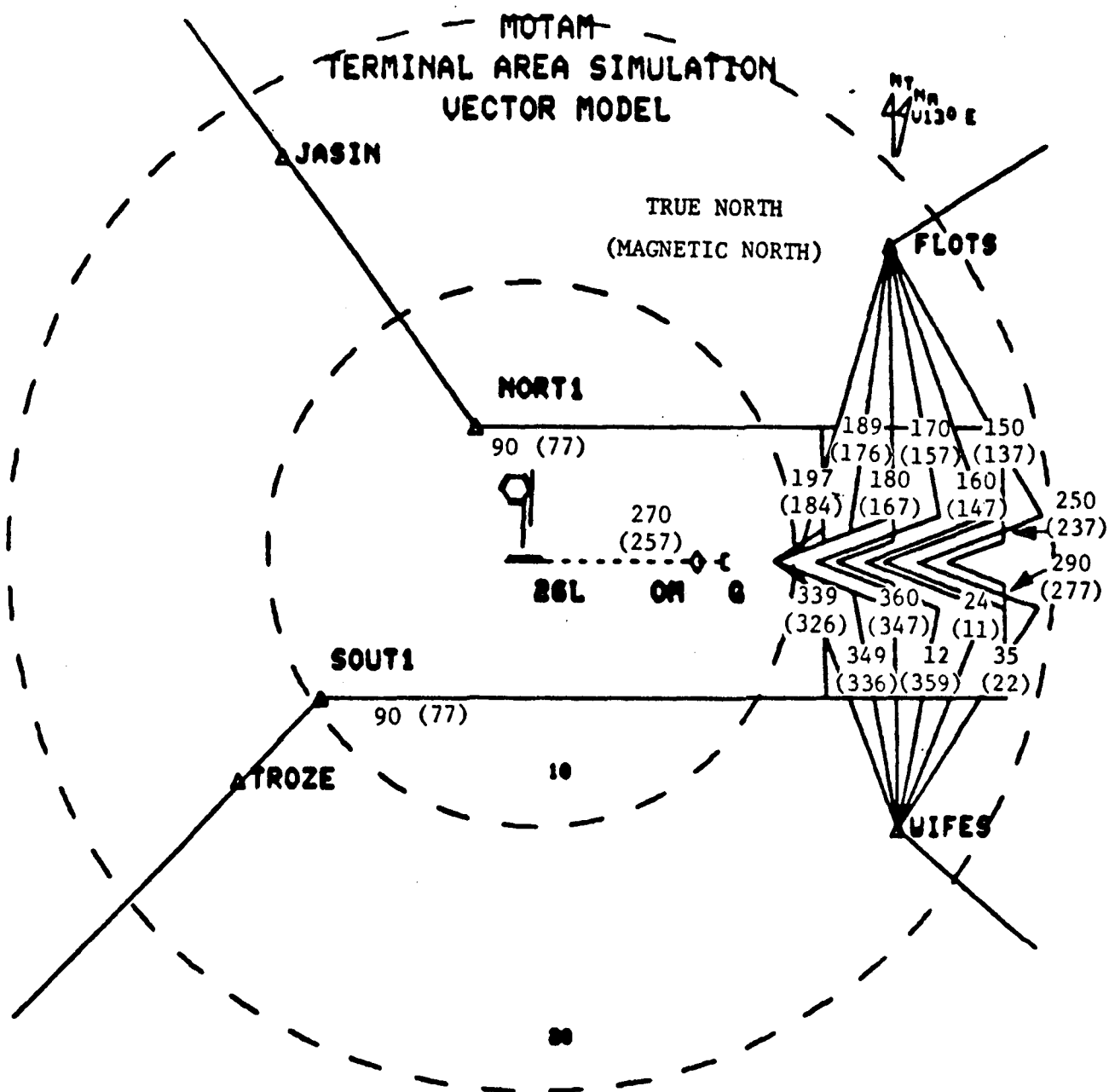


Figure 5. - Expansion of approach area
 vector model flight paths.

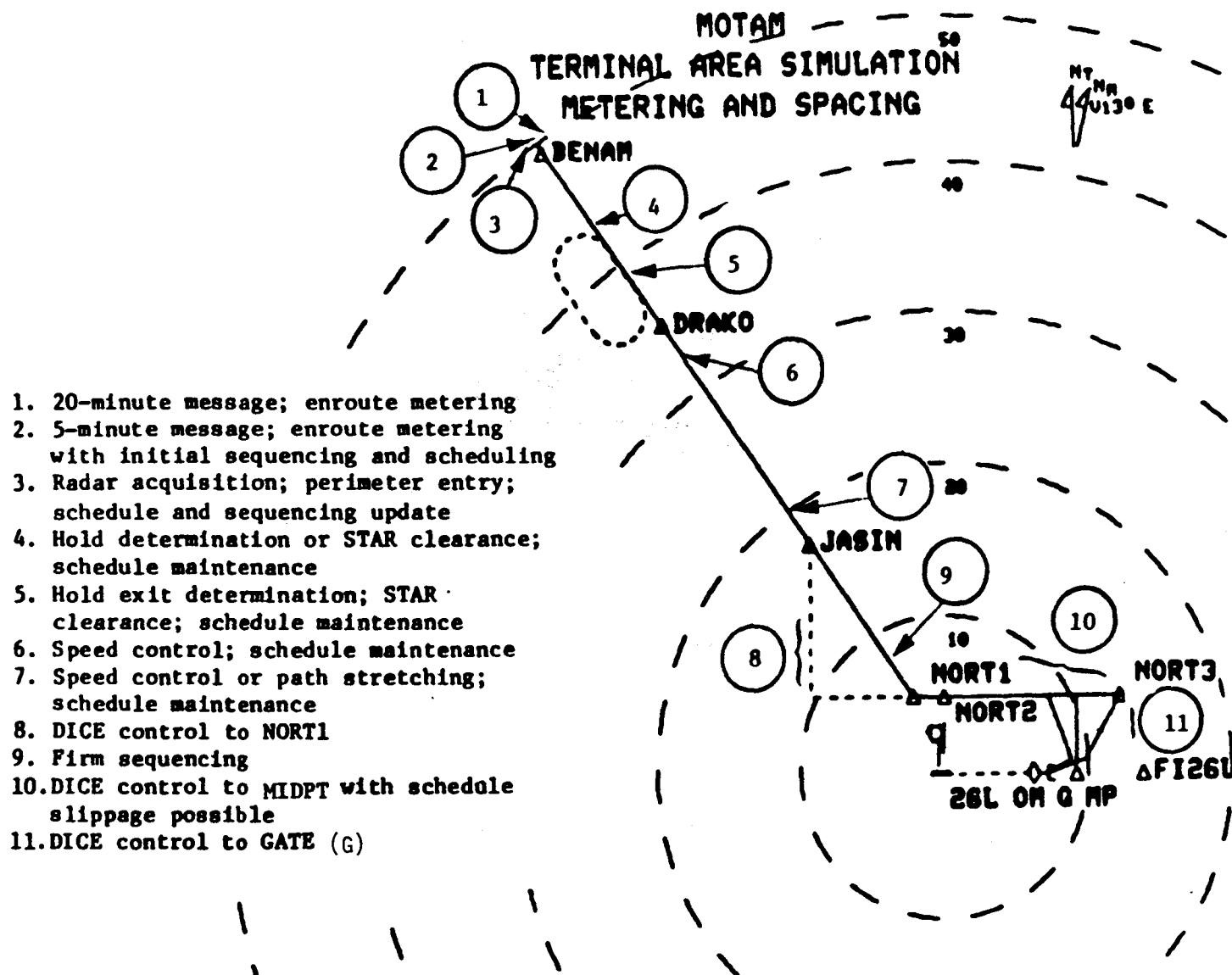


Figure 6. - RNAV model metering and spacing control logic for DRAKO western STAR.

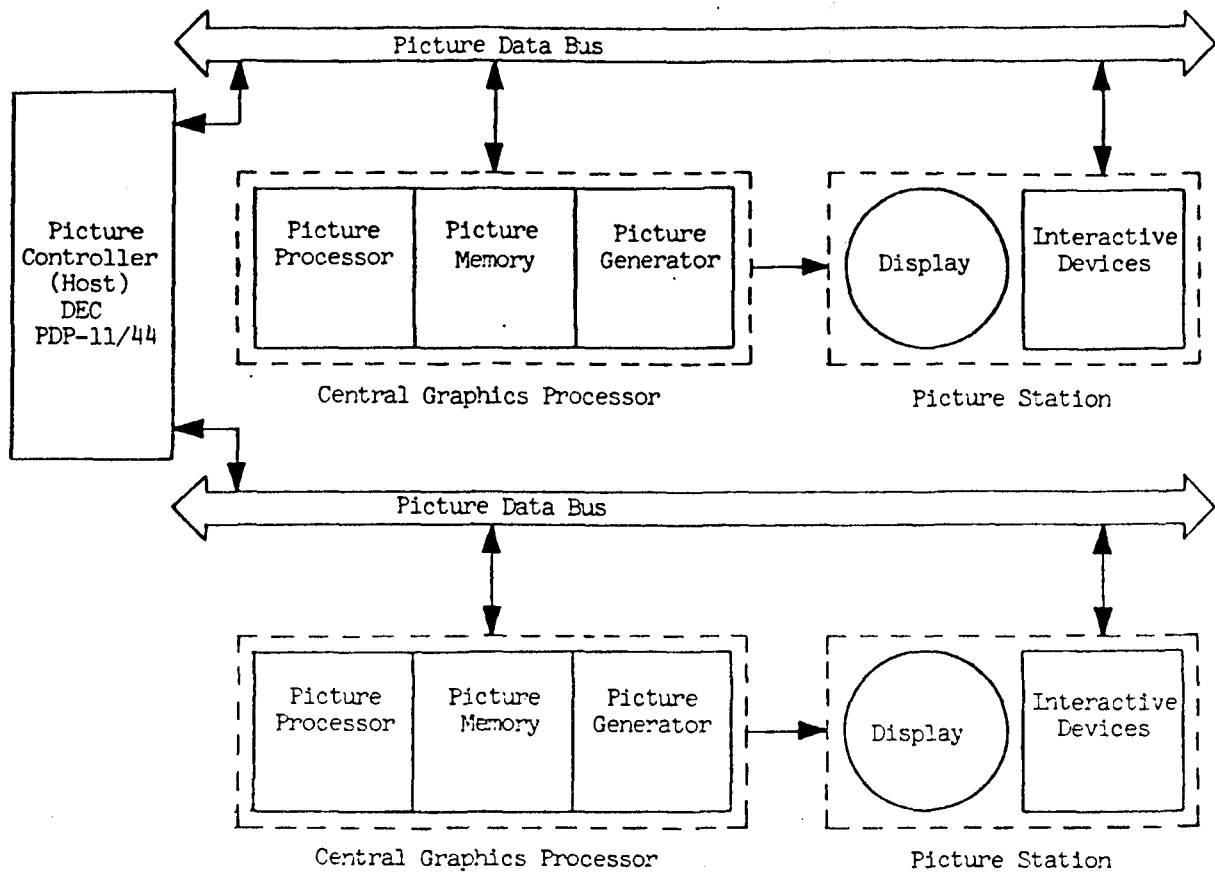


Figure 7. - Sub components and Data Flow of the ATC Display System.

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Figure 8. - Total ATC Display System.

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L-83-7.832

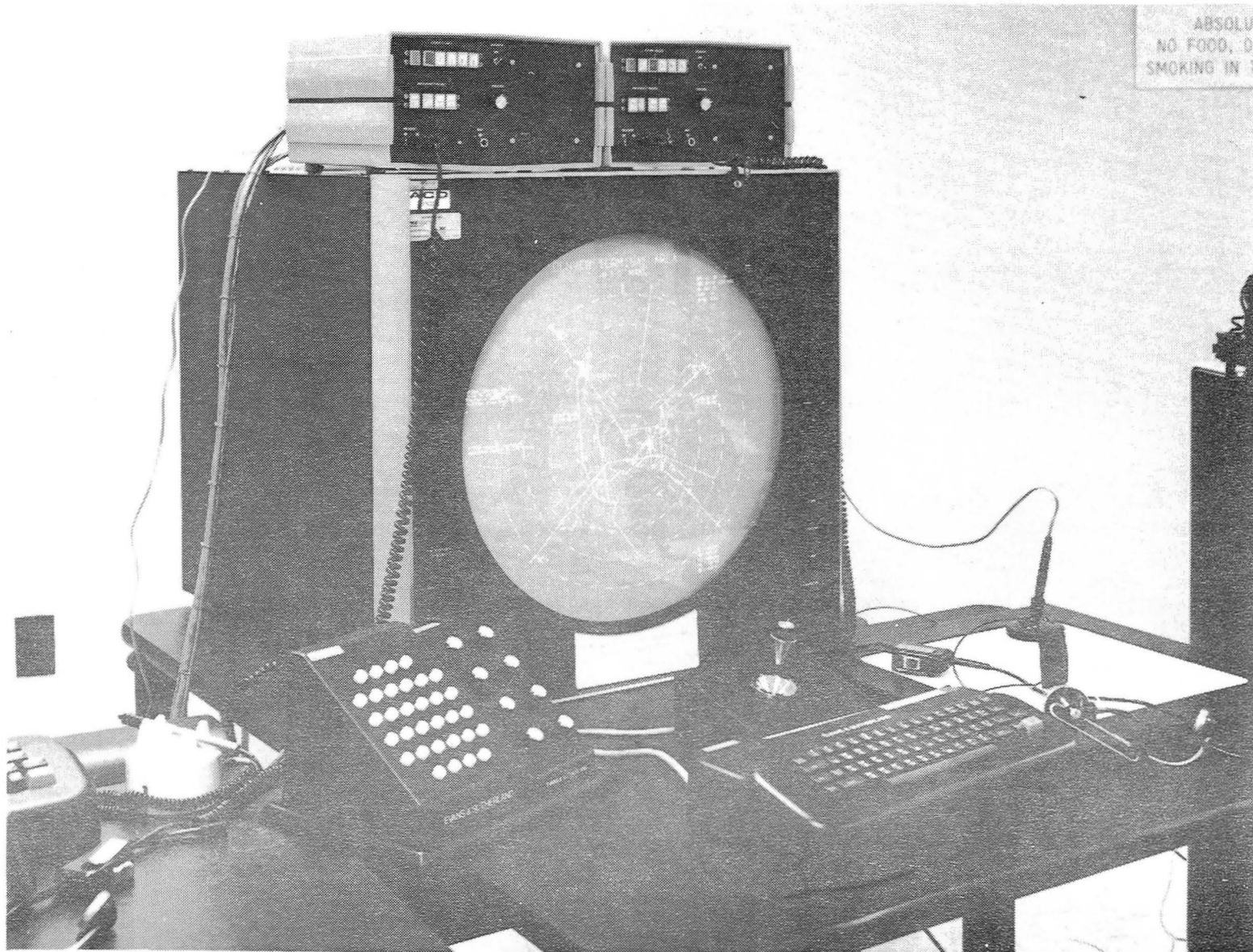


Figure 9. - One MPS with interactive devices.

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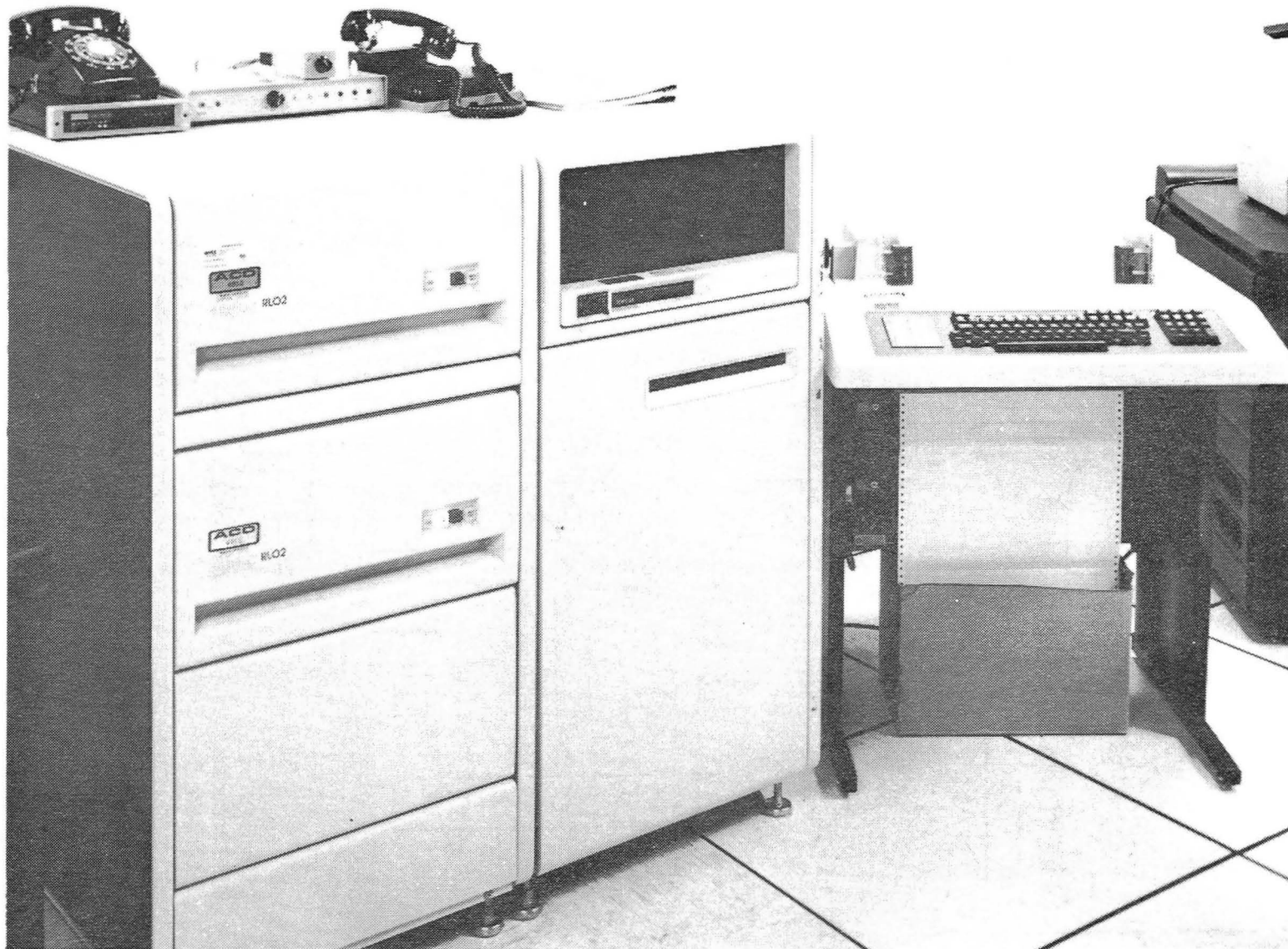


Figure 10. - Host DEC PDP 11/44, dual disk, and DECWRITER.

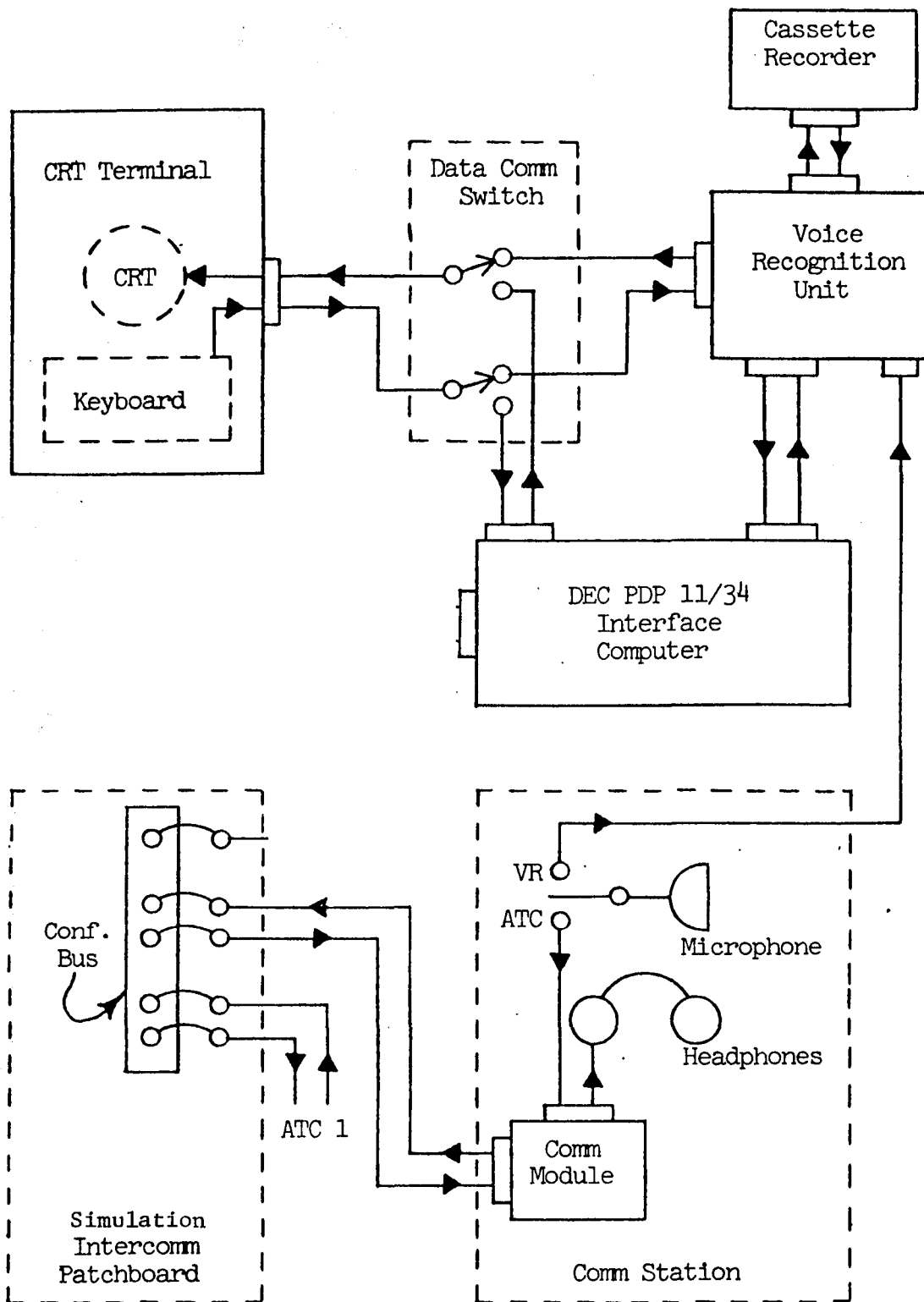


Figure 11. - Typical Pseudo Pilot Station Block Diagram.

	A/C ID	HDG	G/S	A/S	TYPE	ALT	COMMAND	INPUT
1.	WA453	145	260	210	B737	16000	CLEARED	A
2.	FL559	045	270	210	B737	18100	AIRSPEED	B
3.	OZ405	211	170	154	DC9	7200	ALTITUDE	C
4.	UA452	270	120	113	DC10	5400	LEFT	D
5.							RIGHT	E
6.							HOLD	F
7.							DIRECT	G
8.							TYPICAL COMMAND:	
9.							559 AIRSPEED 180	
10.							KEYED INPUT:	
11.							559B180	
12.								
13.								
14.								
15.								

559 AIRSPEED 180
DATA TRANSMITED !!!

Figure 12. - CRT Display Format

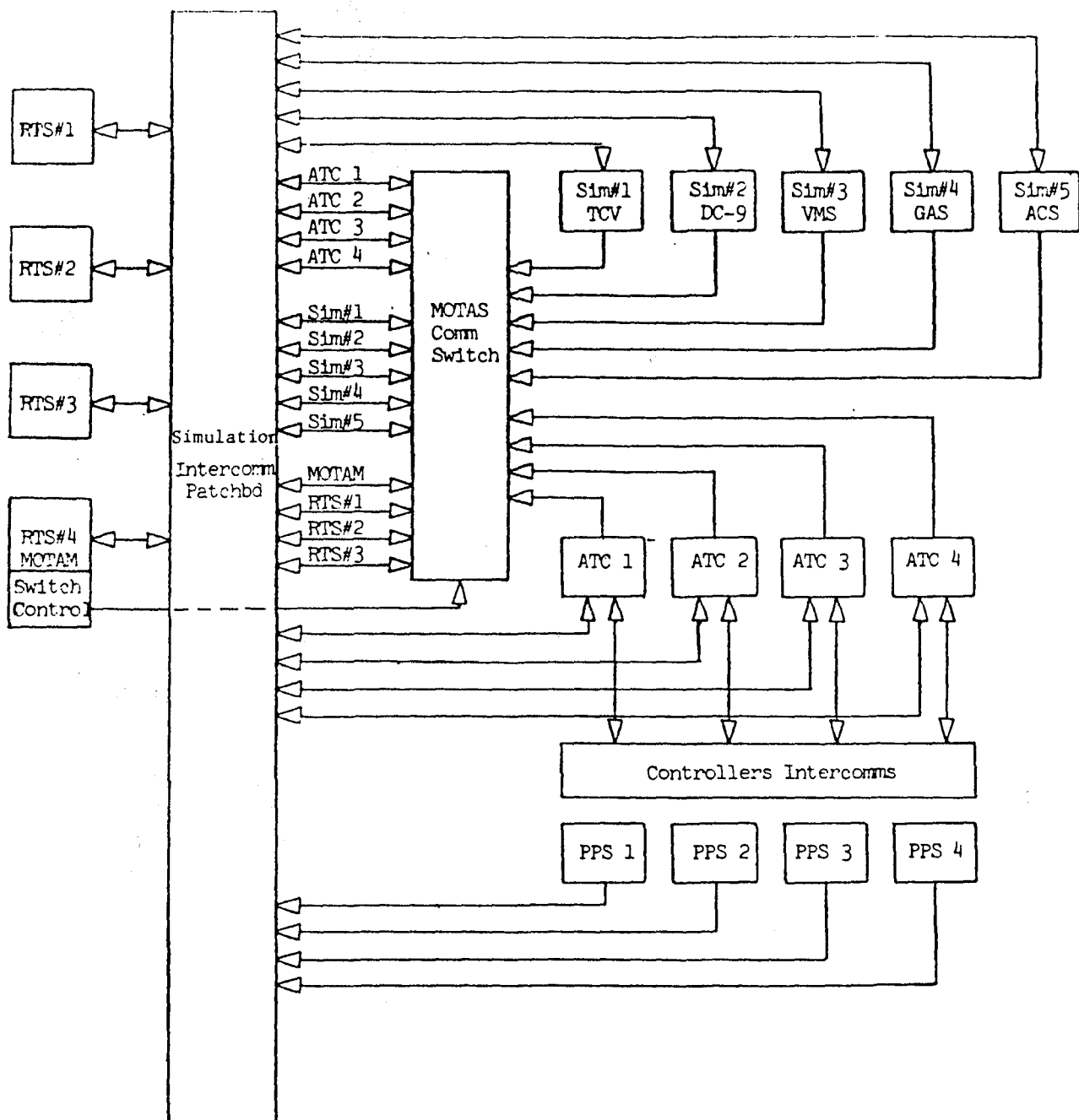


Figure 13. - MOTAS Voice Communication System Block Diagram.

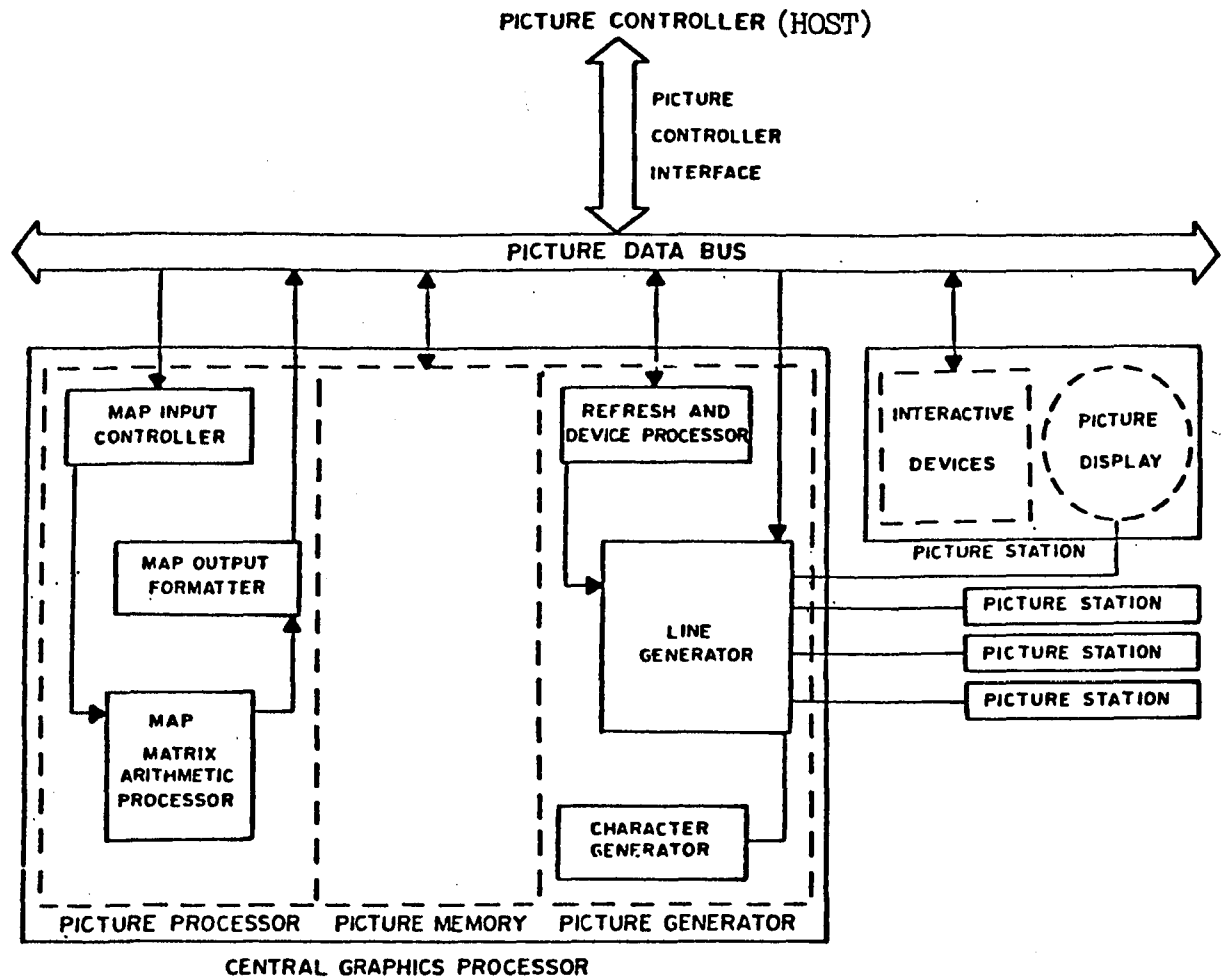


Figure 14. - The Multi Picture System Components.

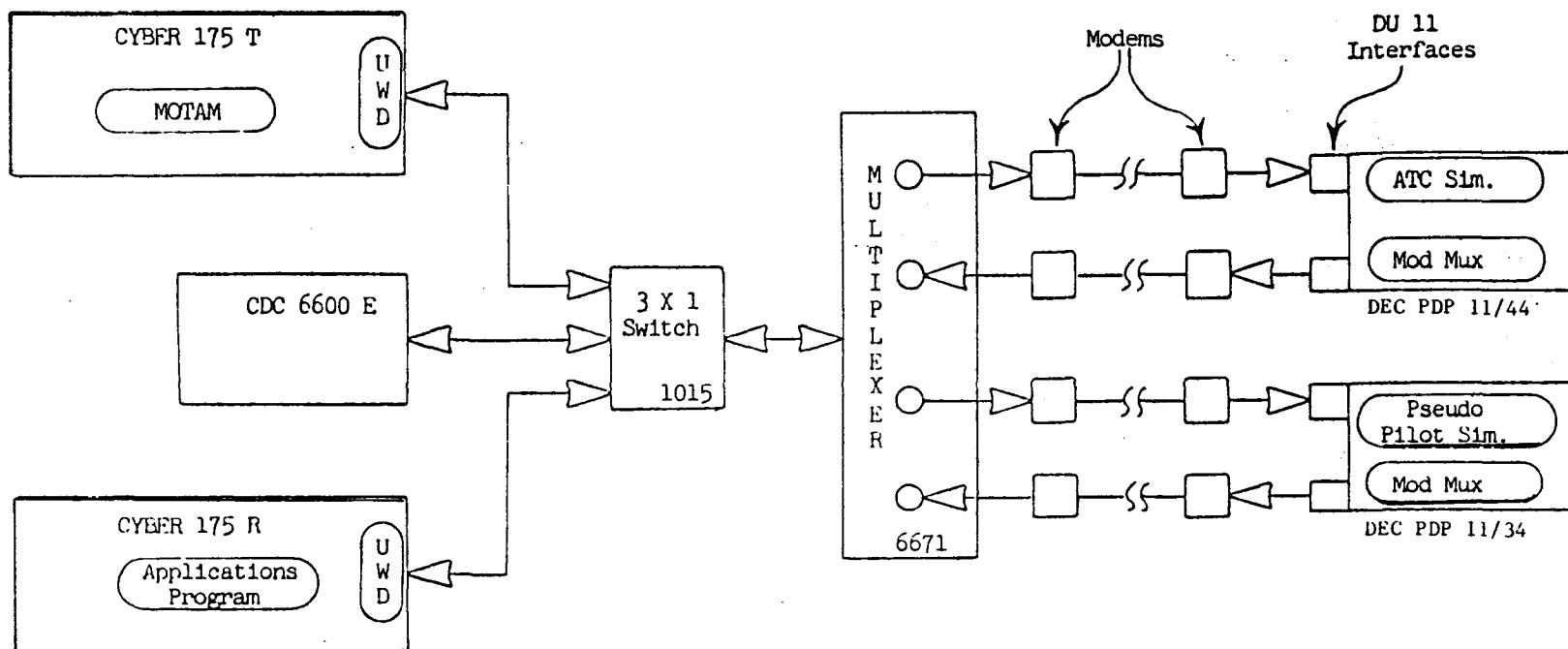


Figure 15. - Data path between CDC CYBER and DEC Computers.

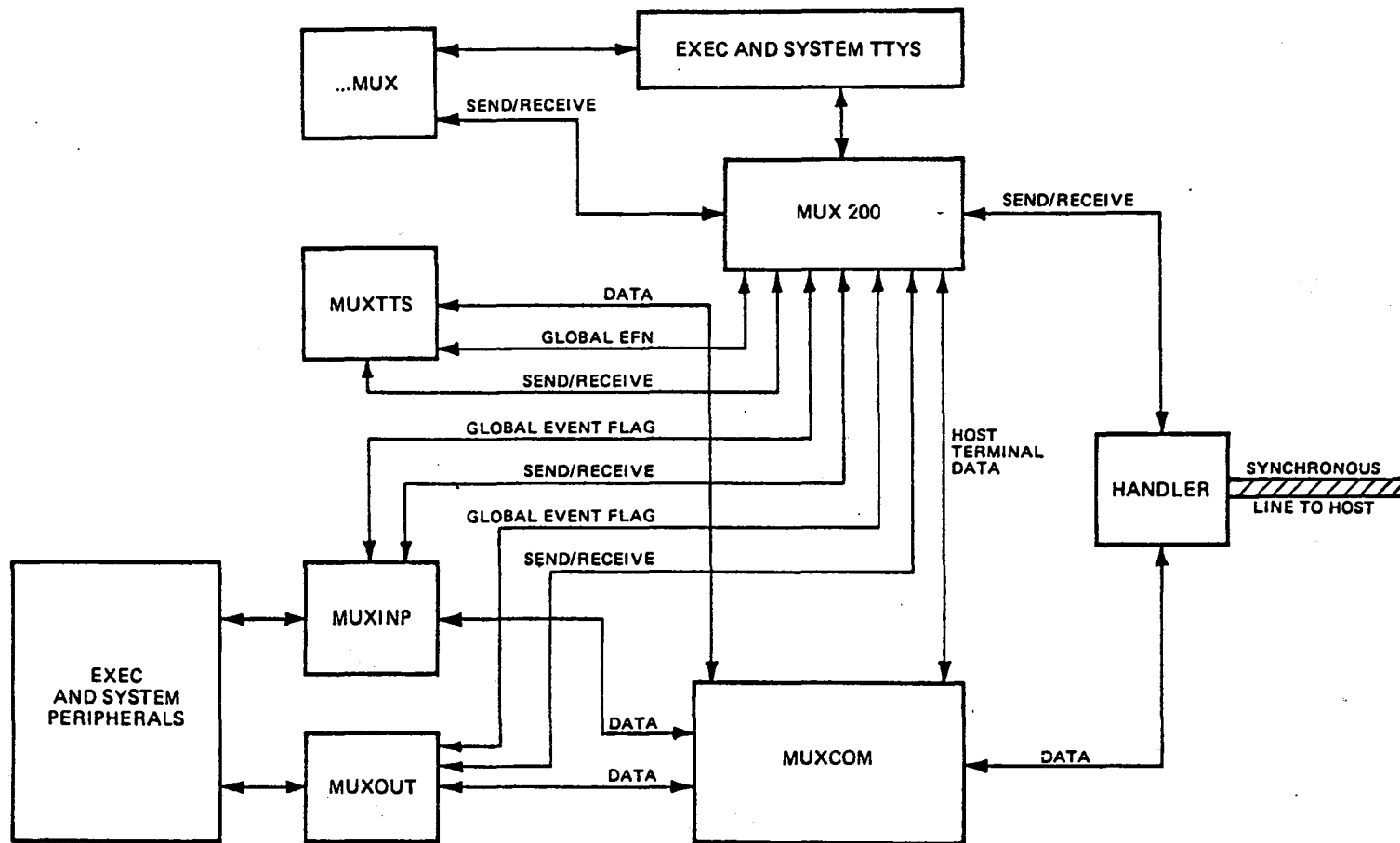


Figure 16. - MUX200 Emulator Task Communication.

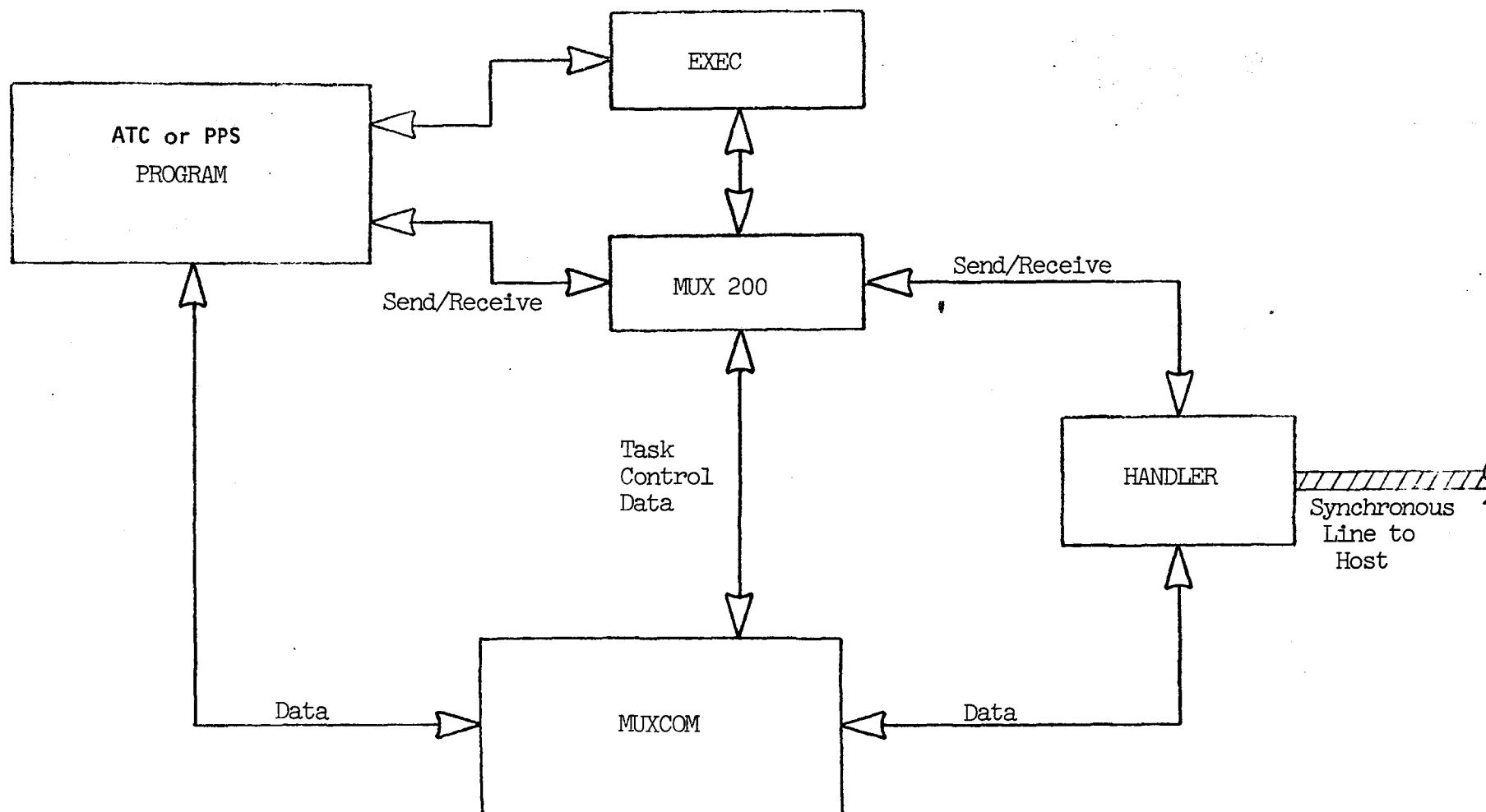


Figure 17. - ATC and PPS Task Communication.

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12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546				14. Sponsoring Agency Code	
15. Supplementary Notes Patricia B. Naftel is associated with Research Triangle Institute.					
16. Abstract The Mission Oriented Terminal Area Simulation (MOTAS) was developed to provide an ATC environment in which flight management and flight operations research studies can be conducted with a high degree of realism. This facility provides a flexible and comprehensive simulation of the airborne, ground-based and communication aspects of the airport terminal area environment. Major elements of the simulation are: an airport terminal area environment model, two air traffic controller stations, several aircraft models and simulator cockpits, four pseudo pilot stations, and a realistic air-ground communications network. MOTAS has been used for one study with the DC-9 simulator and a series of data link studies are planned in the near future. This report includes a description of the major elements of MOTAS and how they were integrated into a system. Also, the capabilities of the overall simulation are discussed.					
17. Key Words (Suggested by Author(s)) Digital Simulation of Terminal Area Model Air Traffic Control Aircraft Cockpit Simulators Pseudo Pilot Stations				18. Distribution Statement Unclassified - Unlimited Subject Category 62	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		22. Price A04	
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